

Perspectives of Textile Wastewater Treatment Using MBR: A review

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Abstract

Membrane Bioreactor (MBR) is used besides municipal wastewater treatment in many industrial scale plants, such as textile sector. It can be operated under normal conditions on a by-pass system, or submerged in the reactor's vessel, where it works in-line and operates by means of vacuum suction at low trans-membrane pressure. In wastewater treatment, MBR's have significant advantages in regard to conditions and quality of the treated water. This work gives basic operation principle of MBR technology for textile wastewater treatment which is very important technology in nowadays environmental protection as well as analyses some advantages and disadvantages of the MBR process compared to the conventional activated sludge process. Membrane fouling and cleaning processes in MBR are also discussed.

Keywords

Textile Wastewater; Membrane Bioreactor; Membrane Fouling

Introduction

The Full-scale commercial aerobic MBR, first appeared in North America in the late 1970s and then in the Japan in the early 1980s. At around the same time, anaerobic MBR processes were introduced to the industrial wastewater market in South Africa. The aerobic MBR was introduced into the Europe in mid-1990a. (Stephenson, 2000).

With the limited natural water resources, reducing water pollution and reclaiming wastewater for reuse purpose have become increasingly critical for resource conservation and sustainable development. Conventional treatment and reuse processes have been used successfully to control various contaminants. Since the regulation of wastewater has noticeably increased in many countries, membrane bioreactor (MBR) can be attractive options for wastewater treatment (Judd, 2011).

The MBR for wastewater treatment has been investigated for over 30 years (Stephenson, 2000). In

recent years, the interest in MBR processes, taking great advantages such as small footprint, low maintenance, complete solid removal from effluent and high quality production over conventional biological activated sludge processes (ASP), has increased significantly.

Advantages and disadvantages of MBR over ASP

During textile dyeing processes, vast quantities of chemicals (dyes, auxiliaries) are consumed, which strongly charges the wastewater. Textile wastewater contains large amounts of *dissolved organic* matter and inorganic substances, high pH value, and a low BOD/COD (biological oxygen demand/chemical oxygen demand) ratio. While the wastewater contains heavy metals, sulphide components, fats, oils and fibres. The residues of non-biodegradable dyes are kept mostly in the wastewater, being the result of incomplete binding of dyes to the textile fibre. The average rate of dye-fixating when dyed with reactive dyes is from 60 to 80%. The residues of non-fixed colours are washed from the textile and thus contaminating the wastewater (Petricin, 2010). Biodegradability of dyes as well as the removal of colour are fully discussed in the literature (Yuzhu, 2001, Pearce, 2003). The anaerobic activated sludge unit is always the first stage in the two-stage biological process. During the anaerobic stage, the azo bonds of the reactive dye are degraded, resulting in a reduction of the colour and the production of toxic colourless aromatic amines. In the following aerobic activated sludge unit, these colourless aromatic amines are then further degraded/mineralized in order to meet the effluent discharge standard criteria (Libra, 2004).

It is advantageous to use a membrane bioreactor (MBR) which combines the benefits of high biomass concentrations with the possibility to run a continuous process at controlled biomass retention. Since membrane costs have decreased dramatically over the

last couple of years to approximately 50 Euro/m² nowadays (Krause, 2003) and energy requirements for aeration of the membrane are also fast approaching the normal ASP range, this has now become an economically feasible solution even for low-profit processes such as wastewater treatment. It has been observed that the aerobic biodegradation is not really economical, due to low removal efficiency for reactive and other anionic soluble dyes. Due to low biodegradability under aerobic condition a large reactor volume is required, while MBR reduce the required reactor volume.

There are several advantages associated with the MBR, which makes it a valuable alternative over other treatment technique. (Krause, 2003).

- Retention of all suspended matter and most soluble compounds within the bioreactor leads to excellent effluent quality capable of meeting stringent discharge requirements and opening the door to direct water reuse.
- The possibility to retain all bacteria and viruses results in a sterile effluent, eliminating extensive disinfection and the corresponding hazards related to disinfection by products.
- Since suspended solids are not lost in the clarification step, total separation and control of solids retention time (SRT) and hydraulic retention time (HRT) are possible.
- Requires a large reactor volume compared to conventional processes significantly reducing plant footprint, which makes it desirable for water recycling application.

Operational Principle

In a typical configuration, a membrane bioreactor is composed of two primary parts, the biological unit responsible for the biodegradation of the waste components and the membrane module for the filtration process of the treated water from mixed liquor. (Melin, 2006).

Presently, two basic MBR systems are distinguishable: side-stream configuration and submerged configuration. A Zenon submerged membrane bioreactor is represented in Fig.1.

The first generation of MBR was side-stream or cross-flow systems. The use of recirculation loops leads to increased energy costs. In addition, the high shear stresses in the tubes and recirculation pumps can contribute to the destruction of bioflocs and this has be

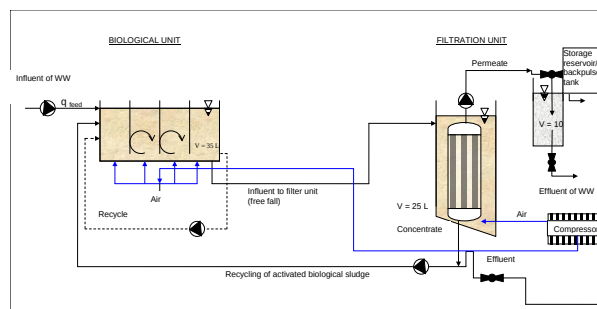


FIG. 1 A SUBMERGED MBR (PETRINIC, 2010)

-en linked to a loss of biological activity (Yamamoto, 19989). To overcome these limits, the submerged MBRs were developed and widely used in wastewater treatment (Yang, 2006). In a submerged MBR, shear stress is created by aeration which not only provides oxygen to the biomass, but also maintains the solids in suspension and scours the membrane surface to alleviate membrane fouling. The normal process of aeration can be used to generate a shear stress on the membrane surface without requiring a recirculation pump. However, it has been found that more than 80% energy consumption was for aeration (Meng, 2008). The type of MBR preferable for textile industry wastewater treatment is the external configuration which is easy to clean. However, the results of the textile wastewater treatment using submerged MBR showed that the removal efficiency of COD and dyes was 90% and 97%, respectively. Wastewater was generated using reactive azo-dyes, such as Drimaren Blau HF-RL, Dimaren Gelb HF-R and Dimaren Rot HF-3B. (Petricnic, 2010).

Membrane Fouling and Fouling Control

Particle separation and water permeation involve various mass transport steps in membrane filtration processes. Mass transfer can be limited by the attachment, accumulation or adsorption of materials on the membrane surface and/or within membranes pores. As a result, increase in hydraulic resistance over time is expected and the phenomenon is called membrane fouling. Different types of fouling mechanisms have been described in MBR applications and the effect of the temperature on membrane fouling (van den Brink, 2011). The formation of scaling on a membrane surface is usually caused by mineral precipitation or deposition and it is not a dominant type of fouling in MBR (Jiang, 2007) except for hard water applications. Bio-fouling refers to biofilm formation on a membrane surface, specially related to microbial cell, aggregates and their bio-products, and which results in an unacceptable degree of membrane

performance. Organic fouling is the association of macro-molecules with the membrane surface or deposition in its pores through the van der Waals forces, hydrogen bonds, electrostatic interaction or strong chemical bonds. Pore blocking refers to the clogging of membrane pores by fine colloids or macro-molecules that are of similar size to that of the membrane pores. Cake formation refers to the development of a layer of colloids or macro-organics on the membrane surface. Many studies have concluded that pore blocking and cake formation are the most common types of fouling for MBR operations (Jiang, 2007).

Chemically, EPS is a pool of complex organic matter that typically consists of carbohydrates (polysaccharides), proteins (including enzymes), humic-like substances, DNA, lipids, nucleic acids and uronic acids. (Dignac, 2000). In general, EPS is classified according to the phase with which it is associated in mixed liquor. (Laspidou, 2002). Despite the fact that the anoxic biofilm contained less EPS, faster bio-fouling was observed in anoxic MBR compared to the aerobic one. It is because not only the amount of EPS, but also the spatial distribution of EPS inside the biofilm may affect membrane filterability (Yun, 2006).

Hai et al (Hai, 2011) demonstrated that bio-augmented membrane bioreactor (MBR) containing a GAC-packed anaerobic zone considerably improved the performance of textile wastewater treatment. In addition to the accomplishment of significant colour, TOC and TN removal, the membrane fouling in this study was rather minimal. Chemical cleaning was first applied after 180 days.

Among biological system anaerobic MBR (AnMBR) with immobilized bio-cells system can be utilized effectively due to its added advantages of low membrane bio-fouling. (You, 2010).

Influent pre-treatment is the first step to prevent certain potential foulants from entering the filtration system. It involves three different mechanisms: physical, chemical and biological one. Most of the physical pre-treatment procedures increase the size of foulants, and chemical pre-treatment reduce the affinity of foulant to membrane surface. Consequently the membrane fouling is shifted to more reversible cake filtration (Drioli, 2010) In textile wastewater treatment MBR was combined with other technologies in order to improve the operation. The addition of adsorbents, such as powdered activated carbon (PAC)

or coagulants such as alum and zeolite, has proved to be effective in the alleviation of membrane fouling in wastewater treatment (Holbrook, 2004, Seo, 2005). Biological step removes or reduces influent debris and those colloidal particles detrimental to a filtration membrane. In addition, influent pH adjustment is also important for the mitigation of membrane fouling due to mineral precipitation. Fouling could be reduced by optimization of operational conditions. Hydrodynamic control of a filtration system to limit fouling includes a sub-critical flux operation, non-continuous filtration operation, constant-flux operation mode, and turbulent aeration/ recirculation. (Hong, 2002) Proper design and operation of an MBR process in order to produce activated sludge mixed liquor with high filterability is a very promising way to limit membrane fouling. There is design and operation of an MBR where so-called Membrane Performance Enhancer MPE can be used beneficially (Wozniak, 2010). The same author claimed that using MPE the operator has a tool to solve fouling problems and lower the investment cost of MBR by 20%.

The requirement of biological aeration is higher than that of CAS because of the lower oxygen transfer rate due to highly concentrated biomass. In MBRs, as in all aerobic wastewater processes, both the biomass characteristics and the design of the aeration system affect oxygen transfer. Air, introduced below the membrane assembly, is supposed to be ideally distributed to optimise air scouring action across the membrane surface. Aeration in MBRs is generally provided by fine bubble aerators situated under the membrane modules which are used to scour and/or gently agitate the membranes, in order to control membrane fouling. (Germain, 2007) However the ideal aeration mode preventing fouling and ideal air flow is unclear today even if numerous studies have claimed that big bubbles would be preferable. (Ueda, 1997) Aeration, as well as very important for mixing in the bioreactor and good contact between the liquid and gas phases, does not allow a dead zone and channelling in the bioreactor. The introduction of a submerged membrane in a bioreactor requires intensive fluid and air bubble movement at the membrane surface. The main objective is to maintain low membrane hydraulic resistance (high porosity) by the action of liquid and air bubble shear forces at the membrane's surface. Similarly the strong shear force breaks-up microbial flocs, reduces the aggregates of waste particles, and enables breakage of suspended

filamentous networks. Removal efficiency depends on factors such as the cross-flow velocity, the membrane filtration flux, and the sludge concentration. (Ueda, 1997, Shimizu, 1996, defrance, 1999) Some studies have been carried-out on the hydrodynamic conditions in a membrane bioreactor. The impact of aeration rate and membrane flux on filtration resistance has been thoroughly investigated. (Ueda, 1997, Chen, 1997, Kwon, 2000) The effect of sludge concentration has been taken into account (Bouhabila, 1998) together with the hydrodynamic effect on membrane fouling in terms of the geometry of an air-lift reactor. (Ueda, 1997, Liu, 2000, Shim, 2002) In addition, MBR works with high concentration of biomass and suspended solids, where parts of the reactor could work as a dead zone and a zone with stagnant water. Such a working mode of MBR has influence on the time the substrate consumes in the reactor, as well as on the rate of contact between in-coming substrate and micro-organisms. Therefore, HRT is very important for the efficiency of MBR. Improving the performance of an existing reactor or studying a new design of MBRs requires modelling of the flow-through bioreactor and determination of the average residence time of the liquid and gas in the reactor.

Membrane materials always show different fouling properties. Common membrane materials are polysulfone, polyether sulfone, polyvinyliden fluoride, polyacrylonitrile, etc. In general, the rate that membrane fouling occurs is more rapid on hydrophobic membranes than that on hydrophilic ones because of the hydrophobic interactions between foulants and membranes. As a result, membranes are modified in order to reduce such interactions and control fouling (Drioli, 2010). Polyvinyliden fluoride PVDF could be modified in such way that prevents irreversible fouling of membrane in MBRs.

Bio-augmented aerobic stage significantly aided decolouration under higher dye-loadings. (Hai, 2011) The overall results (Yigit, 2009) indicated that complex and high polluted textile wastewaters can be treated much more effectively by MBR processes than that by conventional activated sludge systems, and the treated wastewaters by MBRs have high potential for reuse in the textile industry.

A combination of an anaerobic sequencing batch reactor (SBR) followed by an aerobic membrane bioreactor showed excellent COD and true colour removal performance in the anaerobic SBR (Seo, 2005).

Membrane Cleaning and Relaxation

Membrane fouling remains a major operational issue leading to higher operational costs compared to current treatment technologies. Schematic representation of different fouling rates in MBR is seen from Fig. 2.

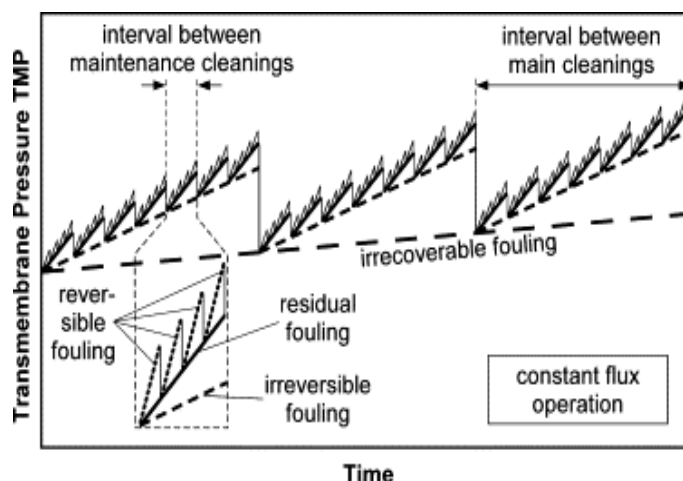


FIG. 2 A SCHEMATIC REPRESENTATION OF DIFFERENT FOULING RATES IN MBR (DREWS, 2010)

To sustain an efficient process, membranes may require frequent cleaning either by physical or chemical means (Stephenson, 2000) Physical cleaning, otherwise referred to as maintenance cleaning, mainly involves mechanical methods such as relaxation, permeate/air back-pulsing and back-flushing (where permeate is pumped in the reverse direction through the membrane). MBR performance is clearly improved by such an intermittent filtration (relaxation). (Hong, 2002) They have been incorporated in most MBR designs as standard operating strategies to limit fouling (Judd, 2011). However, to maintain a given flux productivity, higher instantaneous fluxes are required to compensate for the filtration downtime due to relaxation and backwashing. Many studies have compared the fouling behaviour of MBRs when different fluxes and different physical cleaning intensities are applied. Nevertheless, after each relaxation sequence, the membrane permeability is only partially recovered, indicating that irreversible fouling occurs or that longer relaxation time would be necessary. However, different physical cleaning techniques are rarely tested using the same flux productivity (time average flux), making the efficiency of the filtration modes difficult to assess.

Chemical cleaning is mainly recovery cleaning that usually involves a cleaning step using chemical oxidants such as NaOCl, citric acid $C_6H_8O_7$, H_2O_2 , etc.

(Geng, 2006). During the treatment of denim textile wastewaters, an ex situ chemical cleaning procedure was applied, which included soaking the membrane module in sodium HClO solution of 250 mg/L (as chlorine) for 3 h, then in HCl solution (pH 2) for 5 h, washing the module with tap water, and assembling the module back into the reactor. [34] Optimization of membrane characteristics helps to limit fouling. This can be done by careful selection of the membrane regarding the pore size and distribution, surface charge, hydrophobicity, chemical stability, mechanical strength, module packing density and, eventually, cost. (Jiang, 2007).

Energy Costs

One of the important disadvantages of application of MBR in industrial wastewater treatment process remained the costs for energy demand which amounts to almost 40 % of the MBR lifecycle costs (Judd, 2011). Table 1 presents the advantages and drawbacks of submerged and side stream configurations. As seen from Table 1, aeration costs are very high when using submerged MBR and are reaching up to 90% of energy demand. The operating costs are higher in side stream configuration, while capital costs are higher in submerged one. Thus higher energy costs must be lowered. Considerable progress was made by introducing airlift technique. The main advantage is scouring action created by the rinsing bubbles – these expand when they rise along vertically placed membrane module and such bubble slugs wipe the membrane wall.

TABLE I ADVANTAGES AND DISADVANTAGES OF SUBMERGED AND SIDE STREAM MBR CONFIGURATION [2]

Submerged membranes	Side stream configuration
High Aeration cost (up to 90%)	Low Aeration cost (~20%)
Very low pumping costs (higher if suction pump is used (~28%))	High pumping costs
Lower flux (larger footprint)	Higher flux (smaller footprint)
Less frequent cleaning required	More frequent cleaning required
Lower operating costs	Higher operating costs
Higher capital costs	Lower capital costs

A comparison of the consumption of MBRs in kWh/m³ and the percentage of each apparatus respective to the total consumption was made by Gil et al (Gil, 2010). From Fig 3 it can be seen that the energy consumption is very high. It was calculated that the total consumption was 6.06 and 4.88 kWh/m³ for 19 and 25 LMH, respectively. The values are higher more than 10-times compared with CAS plants. Regarding the energy consumption, the most demanding apparatus is the coarse bubble aerator, followed by the mixer. Aeration comprises almost 50% of the total energy requirements, therefore more effort must be directed towards aeration optimization.

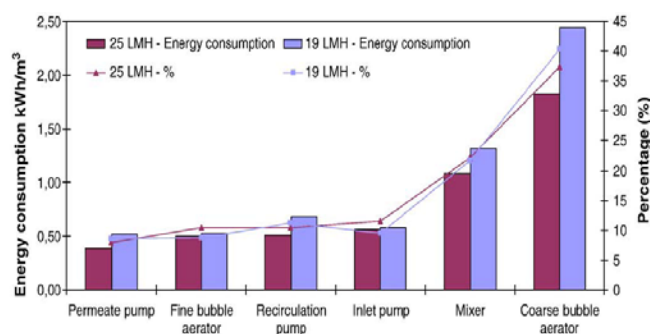


FIG. 3 ENERGY CONSUMPTION IN PILOT PLANT MBR (GIL, 2010)

Conclusion

Despite the limitation imposed by fouling, the future of membrane bioreactors in industrial wastewater treatment seems assured. Further incremental improvements can be expected as more is understood about the interrelationship between biomass characteristics, permanent fouling, and cleaning, and as membrane costs continue to be driven downwards. More significant “quantum leap” improvements are slightly harder to envisaged, however, it remains to be seen whether any profoundly original MBR product will arise from current research and development activity. The effort of recent researches is directed towards new sustainable hybrid MBR technologies for textile wastewater treatment in order to achieve reuse standards. Using an anaerobic-oxic membrane bioreactor followed by reverse osmosis AOMBR/RO process the wastewater could be treated up to level which satisfies EPA wastewater reuse criteria for toilet flushing, landscaping, and irrigation.

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